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An analysis of the technical exigencies and CE marking relative to low voltage (less than 5 kW) photovoltaic inverters marketed in Spain

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ABSTRACT

The objective of this article is to analyse the standards relative to technical exigencies and CE marking that correspond to photovoltaic inverters of low voltage (less than 5 kW) as marketed in Spain. For this study, around 400 different models of inverters from the European market were compiled. Twelve of them, 50 Hz single phase, were chosen, made up of different brands and options of transformer below 5 kW. For these inverters, regulations for each model were examined according to their data sheet specifications, manual and EC Declarations of Conformity. Heterogeneity in compliance to the standards was found. In addition, in view of results obtained it is possible to conclude that it would be wise to establish a common set of standards for every country in the world (or at least a common European normalization) according to PV grid inverters. It would enable all grid inverters to be commercialised in compliance with the same standards everywhere.

Contents

1. Introduction

In recent decades there has been an increasing interest in the use of low-voltage grid-connected PV systems, conditioned by new incentives from different countries. An essential element in those systems is the inverter. Inverters are power electronic devices that are directly connected to the photovoltaic (PV) array (on the DC side) and to the electrical grid (on the AC side), and which essentially convert the DC energy produced by the array into the AC energy required by the grid. In addition to high efficiencies for DC–AC conversion and maximum power point tracking, inverters should produce AC energy at the required quality, with low-total harmonic distortion (THD) of current. As well, there should also be a high-power factor, closed to unity, and a low level of electromagnetic interference, in order to maximize the transfer of energy from the PV array into the grid. Additionally, inverters must also comply with safety requirements for users, equipment and the grid itself.

2. Legal framework for interconnection to the network in Spain

With respect to legislation regarding renewable energy, in the early 1980s Law 82/1980 of 30th December, was passed concerning energy conservation. However, the first PV systems connected to the electrical network in Spain were regulated by Royal Decree 2266/94, where for the first time, the special electrical production system was regulated. The major incentive in

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the electricity market came from the regulation of the sector. Following that, a new general electricity law, the Spanish Power Act 54/1997, dated 27th November, came into force in the Electrical Sector [1], establishing principles for a new model of operation based on free competition, and likewise, boosting the development of energy in special systems. The pressure of the Renewable Energy Sector conditioned the writing and approval of a new decree that regulated, with more detail, the establishment of forms of generation.

Royal Decree 2818 of 1998 [2] carried out Law 54/1997 in the Electricity Sector with modifications introduced by Law 66/1997 of 30th December regarding fiscal, administrative and corporate measures, promoting the development of facilities under a special legal system through the creation of a favourable framework, without incurring discriminatory situations that could limit free competition, while establishing differentiated situations for those energy systems that contribute more efficiently to the above-mentioned objectives. For facilities based on renewable or waste energies, this incentive has no time limit, since their environmental benefits must be internalized and, due to their special characteristics and level of technology, their considerable cost does not allow them to compete in the free market. The incentives which are established for renewable energies are such that they will enable their contribution to the Spanish energy demand to be a minimum of 12% in the year 2010 [3]. Likewise, it provides an advantageous power rate of up to kWh produced by photovoltaic solar facilities connected to the grid. Utilities must buy photovoltaic electricity at 0.4€/kWh for systems of less than 5 kW and at 0.2€/kWh for systems of more than 5 kW. Two years later, the Royal Decree 1663/2000 [4] was approved, which is applied to photovoltaic installations of nominal power of not more than 100 kVA and whose connection to the distribution grid is carried out in low voltage, i.e., not higher than 1 kV. Later, in the Resolution of 31st May 2001 [5], the model for the type of contract and invoice for this systems was established (Fig. 1). Three years later, Royal Decree 436/2004 [6] amended the previous Royal Decree (2818/1998) so as to fit into the existing general framework supporting renewable energy as set out by the Electricity Act 54/1997, which is still in force. It provides incentives for newly installed capacity of renewable energy sources in one of two ways: (1) generators which sell their production to a distributor receive a fixed tariff that is defined as a percentage of a regulated tariff. The percentage was established on a technology by technology basis. The reference tariff for 2007 had a value of 0.440381€/kWh (for PV installations <100 kW) and 0.229764€/kWh (for PV installations >100 kW). (2) Generators which sell their electricity in the free market receive the negotiated market price of electricity, an incentive for participating, and a premium, if eligible.

However, on 25 May a new Royal Decree 661/2007 [6], regulating the production of electricity in the special regime was published. It established new energy tariffs from 1 January 2008. The tariff system was divided into three types, depending on size of the installation: for $P \leq 100$ kW 0.455134 for the first 25 years (0.364107 from then on); 100 kW $< P \leq$ 10 MW 0.431486 for the fist 25 years (0.345189 from then on); 10 MW $< P \leq$ 50 MW 0.237461 for the fist 25 years (0.189969 from then on). The tariffs will be updated every year according to the CPI until 2012.

Also, in Spain, the Electrotechnical Regulation of low voltage is applicable to this sector [7], as well as particular specifications from autonomous communities (the regions) and the distributing company.

3. Technical requirements relative to the photovoltaic grid inverters

With the object of verifying the technical requirements met in the photovoltaic low-voltage grid inverters of less than 5 kW, 391 different inverter models were compiled. Twelve of them were selected. There were 50 Hz single-phase inverters of around 5 kW (according to the transformer options: 50 Hz LF transformers, HF transformers or transformerless), selected from the European market. In Table 1 their most important features are shown. Data sheet specifications, manual and EC Declaration of Conformity

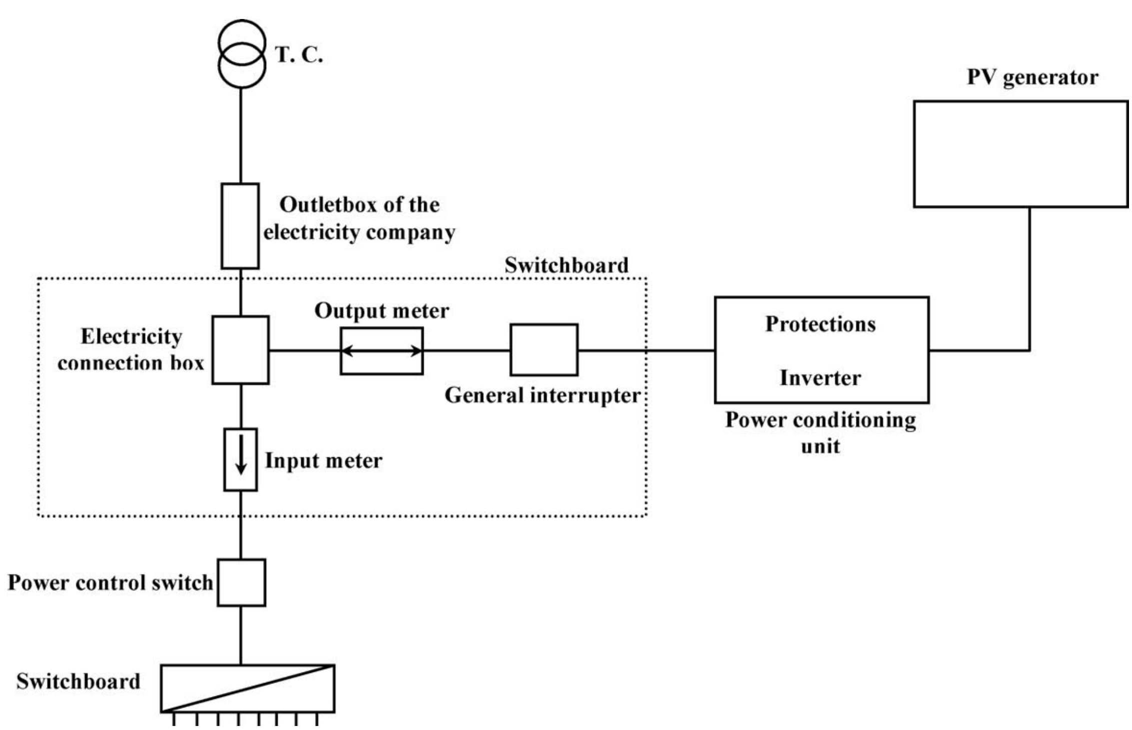

Fig. 1. Scheme detailed in the Resolution of 31st May 2001, to be applied to low-voltage small grid-connected PV systems connected to the public network, in Spain [5].

Table 1
Nominal power and maximum power of inverters selected.

Inverter type	Model	Pn (W)	Pmax (W)
LF transformer	A	2500	2500
	B	5000	5400
	C	2500	2500
HF transformer	D	2500	2650
	E	3000	3600
	F	3000	3000
	G	2600	2750
Transformerless	H	4600	5000
	I	2300	2500
	J	3000	3300
	K	2500	2750
	L	3300	3300

Table 3
Modification of Table 2 as the seven standards related to electromagnetic compatibility were put in force.

Inverter type	Model	EN 61000-6-1	EN 61000-6-2	EN 61000-6-3	EN 61000-6-4
LF	A	YES		YES	
LF	B			YES	
LF	C	YES	YES	YES	YES
HF	D		YES	YES	
HF	E	YES	YES	YES	
HF	F	YES		YES	
HF	G		YES	YES	
Transformerless	H				
Transformerless	I		YES	YES	
Transformerless	J	YES	YES	YES	YES
Transformerless	K	YES		YES	
Transformerless	L		YES		

were examined, noting which regulations were met for each of the 12 grid inverters.

With respect to data sheet specifications it has been possible to verify that in almost all of them they are structured in the following way: electrical, environmental and mechanical specifications and compliance to standards.

Accordingly, the standards of compliance often include European directives, type of enclosure, type of harmonic emission, immunity of electromagnetic compatibility, emission, standards of security, isolation and control of network.

Thus, in all models, except A, said compliance exists with Low-Voltage Equipment Directive 73/23/EC Directive (from 12 December 2006, Directive 2006/95/EC) [8]. Nevertheless, each manufacturer implements this directive in a different way. Whereas, brand G simply mentions compliance with 73/23/EC Directive, the rest of the manufacturers note that regulations are in agreement with that directive. Furthermore, all models studied except A and G comply with EN 50178 [9] that is based on the electronic equipment for use in power installations. As is said in this regulation, compliance with EN 50178 implies immediate agreement with Directive 2006/95/EC. In addition, E and K models are in compliance with EN 60146-1 [10].

Another law applicable is the Directive 2004/108/EU [11] concerning electromagnetic compatibility (EMC). It is a European directive and replaces its predecessor, 89/336/EEC from 20 July 2007. The aim of the EMC is to give protection against electromagnetic interference from equipment.

European standards related with EMC are classified into three different groups: generic standards, basic standards and product and product family standards. Every standard should be used depending on the specific product. Specifically, as with PV grid-connected inverters, there are no specific product standards applicable other than generic standards and basic standards must be followed.

Generic standards define limits for the emission and susceptibility (immunity) of electronic devices, for our case PV grid-connected inverters. Currently, the following generic standards exist: EN 61000-6-1 and EN 61000-6-2, which are related with immunity, and EN 61000-6-3 and EN 61000-6-4,which are linked to standards with emissions. Within every group standards can be distinguished in relation to their environment. Therefore EN 61000-6-1 and EN 61000-6-3 standards talk about Residential, Commercial and Light Industry environment. However EN 61000-6-2 and EN 61000-6-4 talk about Industrial environment. This means that with equipment used in an industrial environment, higher level of emissions are allowed.

EN 61000-6-1 and EN 61000-6-2 are valid for 0–400 GHz of frequency. But, only the EN 61000-6-2 is in agreement with essential requirements of 4b) of 89/336/CE and article 3.1b) (only immunity) about 1999/5/CE Directive.

The test levels of EN 61000-6-2: 1999 are equal to or higher than the requirements found in EN 50082.

In addition, generic standards and basic standards were analysed for the 12 inverters. Again, each manufacturer interprets these in a different way.

Table 2 shows the manufacturer's compliance with seven different standards: EN 50081-1 [12], EN 50082-1 [13], EN 50082-2 [14], EN 61000-6-1 [15], EN 61000-6-2 [16], EN 61000-6-3 [17] and EN 61000-6-4 [18]. However, these norms, in fact are reduced to four, see Table 3 since EN 50081-1 [12] standard was countermanded in 2002 by EN 61000-6-3 [17]; EN 50082-1 [13] also was cancelled in 1994 and replaced by EN 55024 (for equipment of

Table 2
Standards found, related to electromagnetic compatibility, as data sheet specifications, manual and EC Declaration of Conformity were checked for 12 PV grid-connected inverters.

Inverter type	Model	EN 50081-1	EN 50082-1	EN 50082-2	EN 61000-6-1	EN 61000-6-2	EN 61000-6-3	EN 61000-6-4
LF	A	YES	YES					
LF	B						YES	
LF	C				YES	YES	YES	YES
HF	D	YES		YES				
HF	E	YES		YES	YES	YES	YES	
HF	F				YES		YES	
HF	G	YES		YES				
Transformerless	H							
Transformerless	I					YES	YES	
Transformerless	J				YES	YES	YES	YES
Transformerless	K	YES	YES					
Transformerless	L			YES				

technological information) and by EN 61000-6-1: 2001 [15]; and EN 50082-2 [14] also was cancelled in 2000 and replaced by EN 61000-6-2 [16].

Thus according to Table 3, it can be seen that there are inverters (models D, G and I) that are in agreement with immunity standards for industrial environment (and not for Residential, Commercial and Light Industry) but say in compliance with emissions standard for Residential, Commercial and Light Industry but not with Industrial environment. Moreover, there are only two models (C and J) that stay in compliance with the four standards (consequently they can be used in both environments). Furthermore, there is a model, H, that says nothing about these generic standards.

On the other hand, there are two models (A and K) that stay in compliance only with standards related with Residential, Commercial and Light Industry environment. Finally, there is only one model, B, that stays in compliance only with the standard related with emissions in Residential, Commercial and Light Industry environment.

Basic standards provide general information and relate to disturbance phenomena and testing and measuring techniques. They deal with measurements of susceptibility against static discharges, transient phenomena, voltage spikes, voltage drops, voltage variations, immunity against radiated electromagnetic fields, immunity against radiated electromagnetic fields, etc.

When basic standards are analysed for the 12 PV grid-connected inverters from Table 1 it can be proven that their application is interpreted in 15 different ways (Table 4): EN 61000-3-2 [19], EN 61000-3-3 [20], EN 61000-4-2 [21], EN 61000-4-3 [22], EN 61000-4-4 [23], EN 61000-4-5 [24], EN 61000-4-6 [25], EN 61000-4-8 [26], EN 61000-4-11 [27], ENV 50204 [28], IN 55011 [29], 55014-1 [30], 55014-2 [31], EN 55022 [32] and VDE 0871 [33]. Nevertheless as ENV 50204 [28] was cancelled and replaced by EN 61000-4-3: 2003 [22] in fact there are 14 different norms.

Basically, these standards can be divided into two groups: standards with reference to limits of emissions (EN 61000-3-2 and EN 61000-3-3) and testing and measurement techniques (EN 61000-4-X series).

With regard to standards relating to emissions two standards are mentioned: EN 61000-3-2 (in order to offer limits for harmonic current emissions, equipment input current ≤16 A per phase) and EN 61000-3-2 (related to the limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current ≤16 A per phase and not subject to conditional connection). Models C, E, F, H, J and L stay in compliance with both standards. Models A and I do not mention neither of both standards. Models B, D and K say in compliance only to EN 61000-3-2 whereas the G model says in compliance only to EN 61000-3-3.

Concerning EN 61000-4-X the following tests are mentioned: series electrostatic discharge, radiated, radio-frequency, electromagnetic field immunity, electrical fast transient/burst immunity, surge immunity, immunity to conducted disturbances, induced by radio-frequency fields, power frequency magnetic field immunity, voltage dips, short interruptions and voltage variations immunity tests.

As can be observed only E, H and L models stay in compliance with EN 61000-4-2, 61000-4-3, 61000-4-4 and 61000-4-6. The 61000-4-5 is only complied with by E model; the 61000-4-8 is only complied with by L model. Finally, the 61000-4-11 standard is only complied with by E and H models.

On the other hand, in addition to low voltage and electromagnetic compatibility regulations, manufacturers say they comply with other types of regulations. Along these lines, E manufacturer complies with security regulation EN 60664-1 [34] and EN 60950 [35].

Table 4
Standards found, related to basic standards, as data sheet specifications, manual and EC Declaration of Conformity were checked for 12 PV grid-connected inverters.

Inverter type	Model	EN 610003-2	EN 61000-3-3	EN 61000-4-2	EN 61000-4-3	EN 61000-4-4	EN 61000-4-5	EN 61000-4-6	EN 61000-4-8	EN 61000-4-11	ENV 50204	EN 55011	EN 55014-1	EN 55014-2	EN 55022	VDE 0871
LF	A															
LF	B	YES														
LF	C	YES	YES												YES	
HF	D	YES														
HF	E	YES	YES	YES	YES	YES	YES	YES		YES	YES	YES		YES	YES	
HF	F	YES	YES													
HF	G		YES									YES		YES	YES	YES
Transformerless	H	YES	YES	YES	YES	YES		YES		YES			YES	YES		
Transformerless	I															
Transformerless	J	YES	YES												YES	
Transformerless	K	YES														
Transformerless	L	YES	YES	YES	YES	YES		YES	YES			YES	YES			

Table 5
Inverters comply with is related to specifications for degrees of protection according to EN 60529 [35].

Inverter type	Model	Degrees of protection
LF	A	IP20
LF	B	IP54
LF	C	IP65
HF	D	IP21
HF	E	IP21
HF	F	IP21
HF	G	IP23
Transformerless	H	IP54
Transformerless	I	IP21
Transformerless	J	IP65
Transformerless	K	IP54
Transformerless	L	IP54

Finally, the only standard that all the inverters comply with is related to specifications for degrees of protection by enclosures. That is to say, electrical appliances provide against the intrusion of solid objects or dust, accidental contact, and water, EN 60529 [36]. This is defined by the so-called IP Code which consists of the letters IP followed by two digits and an optional letter. The digits indicate conformity with conditions. The first digit indicates the level of protection that the enclosure provides against access to hazardous parts (e.g., electrical conductors, moving parts) and the ingress of solid foreign objects. The latter digit indicates the protection of the equipment inside the enclosure against harmful ingress of water. However, five types of levels of protection have been found: IP20, IP21, IP23, IP54 and IP65 (Table 5). It means that all inverters have some degree of protection but that not all inverters have the same protection. Thus, all inverters will not be able to be installed in the same plots.

4. Conclusions

According with the results obtained the following conclusions might be extracted: there is great heterogeneity in compliance with standards found when 12 PV grid-connected inverters, made up of different brands and options of transformers below 5 kW, were analysed. These usually refer to the standards that are related to aspects such as European directives, type of enclosure, type of harmonic emission, immunity of electromagnetic compatibility, emission, standard of security, and isolation and control of network.

With respect to directive related with electromagnetic compatibility and grid-connected inverters two groups of standards have been found: generic and basic standards. No specific product standards were found. Within of generic standards four different standards were found. Every one is linked to different aspects (emission or susceptibility) and environment (Residential, Commercial and Light Industry or Industrial). From data obtained could be concluded that not all inverters might be installed in all environments. Moreover, only two models say that compliance with four standards.

Within basic standards, 15 of them have been able to be distinguished from different models. Standards related to limits of emissions and testing and measurement techniques have been found. Nonetheless, every one of 15 standards is related to a different subject. An important matter is that two models, A and I, do not mention neither of standards related with limits of emissions (neither current nor voltage). And standards concerning to testing and measurement techniques

Compliance by all is only asserted regarding the norm when referring to the level of protection, although with different levels of protection.

In view of results obtained it is possible to conclude that it would be wise to establish a common set of standards for every country in the world (or at least a common European normalization) according to PV grid inverters. It would enable all grid inverters to be commercialised in compliance with the same standards everywhere.

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